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Uptake of halloysite clay nanotubes by human cells: Colourimetric viability tests and microscopy study

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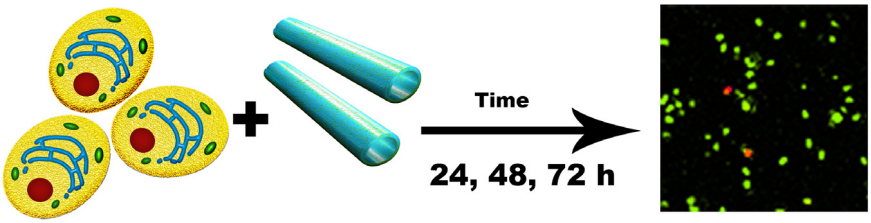
GRAPHICAL ABSTRACT



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ABSTRACT

This study is a systemic investigation of the uptake and toxicity of halloysite nanotubes using human adenocarcinoma epithelial cells (A549). A549 cells were chosen as a popular model of cancer cells extensively studied in nanotoxicity and drug delivery research. The adverse effects of a range of halloysite concentrations were evaluated. The viability of A549 cells was determined using several colourimetric assays. Dark-field microscopy was used to visualize the uptake and distribution of halloysite nanotubes in cells. The morphology of the cells was evaluated using dark-field, transmission electron and atomic force microscopies. The results showed that halloysite had a dose-dependent effect on human cells at concentrations of 5–900 μg per 10^5 cells in the MTT assay. The reduced toxicity of halloysite nanotubes at lower concentrations (5–75 μg per 10^5 cells) was additionally supported by the results of other colorimetric assays. Microscopy assays have demonstrated that the nanotubes, though affecting the biochemical processes, do not alter the morphology of the cells and do not penetrate into the nuclei.

1. Introduction

Nanomaterials are regarded to be a highly promising class of materials due to the global tendency for miniaturization in all fields of production. Nanomaterials application in various aspects of human life will certainly extend over time and become ubiquitous, and inevitably, human exposure to nanomaterials will grow. Physicochemical properties of materials at the nanoscale are different from those of the bulk materials, so new studies on toxicity and interaction of nanoscale materials with living cells are required [1]. The assessment of cytotoxicity of various nanomaterials in the *in vitro* models has become important [2–11]. For example, cancer cell lines have widely been applied for studying toxicity of nickel nanoparticles [12] or gold nanorods [13]. In biomedicine, nanomaterials are considered as perspective drug-delivery systems with nanotubes standing out among all the forms of nanomaterials because of their hollow structure and stability. However, a comprehensive toxicity testing is required prior to any medical application. For example, multiwalled carbon nanotubes are most unlikely to by applied in medicine due to their toxicity [14,15]. Note that nanomaterials have been prominently applied in different spheres of science and industry [16–29].

Among numerous nanomaterials, gaining popularity as drug delivery vehicles, halloysite nanotubes have attracted the enormous attention of researchers worldwide due to their remarkable structural and functional properties [30]. In particular, halloysite

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